Title : Regional climate simulation and prediction of summer precipitation over the central and the southwestern United States and Mexico

Project Duration: May 1, 2002- April 30,2005

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Accomplishments: Period: Oct 2002-Dec 2003

1. Establish near real time monitoring of hydro-meteorological conditions based on the GDAS. The data and web page will be updated daily. During the next year, the monitoring will support the NAME field campaign.
2. Improve the RSM by correcting the mean biases.
3. Identify precipitation regimes over North America.
4. Examine the relationships between the low level jets and summer precipitation regimes over North America.
5. Examine the tropical influence and the influence of soil moisture on the precipitation regimes over North America.

Publications:

Kanamitsu, M., and K. C. Mo 2003: Dynamical effect of land surface processes on summer precipitation over the Southwestern United States. J. Climate, 16, 496-509.

Mo, K. C., and H. M. Henry Juang 2003: Influence of sea temperature anomalies in the Gulf of California on North American monsoon rainfall. J. Geophy. Res. 108, doi:10.1029/2002JD002403.

Mo, K. C., and H. M. Juang 2003: Relationships between soil moisture and summer precipitation over the Great Plains and the Southwest, JGR-Atmosphere 108, doi:10.1029/2002JD002952

Mo, K. C., and E. H. Berbery 2003: The role of the low-level jets and summer precipitation regimes over North America. JGR-atmosphere submitted

Mo, K. C., 2003: Linkages between Warm Season Precipitation over North America and Tropical Intraseasonal Variation. Mon. Wea. Rev. submitted

Mo, K. C. and J. N. Paegle 2003: Intraseasonal variability in the Pan American region. A chapter in a book on Intraseasonal variability Edited by W. K. Lau.

Mo, K. C. 2003: Influence of tropical convection and soil moisture on summer precipitation regimes over North America. The paper will be presented during the Climate Diagnostics and Prediction Workshop in Reno. The manuscript is in preparation.

In the following sections, we will highlight the accomplishments for the past year.

1. **Near real time monitoring of hydro-meteorological conditions based on the GDAS**

The model used for the NCEP GDAS (the Global forecast model GFS) has the horizontal resolution about 0.5 degrees and 64 levels in the vertical. The model is able to capture many meso-scale features. For example: the GDAS is able to capture both the low level jet from the Gulf of Mexico (GPLLJ) and the low level jet from the Gulf of California (GCLLJ). Therefore, the GDAS outputs are well suited for real time hydro meteorological monitoring. The web site is:

http://www.cpc.ncep.noaa.gov/products/NAmonsoon

Based on the GDAS analysis and 6h forecasts and satellite data, we monitor the evolution of precipitation (P), evaporation (E), vertically integrated moisture fluxes [qu, qv] and the vertical profile of qv along with the atmospheric conditions like heights, upper and lower level winds. It will continue through the winter months, but the design will be slightly different. During winter, heavy rainfall areas are located over the west coast of North America and the Southeast. The moisture fluxes responsible for the winter precipitation come mostly from the Pacific and from the Gulf of Mexico. There is no low level jet. Therefore, we will shift the domain westward to cover the North Pacific. During winter, tropical convection plays a major role in determining the precipitation over the western region. Therefore, we will also monitor the pentad mean OLR anomalies for winter.

The summer page covers the months from 1May to 31October and the winter page covers the period from 1November to 30April. The summer monitoring page will be on line starting 1 May 2004 in support of the NAME field experiment.

2. Improve the RSM : Implement the mean bias correction

From the NAMAP experiment, we realize that the simulated rainfall from the RSM depends on the location of the domain and the domain size. The inconsistency is due to the lack of conservation of the mean mass. Improvements have been made to correct the mean biases. The bias is the difference between the RSM base field and the field from the reanalysis 2, which provides the boundary conditions for the RSM simulation. After the mean bias correction is applied at each time step. The simulation improves. An example is given below for the 1990 August, which was a wet month over the Southwest with a maximum of 4 mm day^{-1} over western Arizona

The difference between two experiments (Fig. 1) is the location of the domain. When the domain is shifted 3 degrees to the west, the precipitation pattern changes. The western Arizona is very dry for the domain (18-38ºN,103-121ºW).

After the mean bias correction, the differences between simulated P for two domains are smaller (Fig.2). Both show a band of heavy precipitation located over the western slopes of the SMO. These features are better organized than before. The simulation for the domain (18-38ºN, 101-117ºW) still has more precipitation over Arizona, but the differences are small than before.
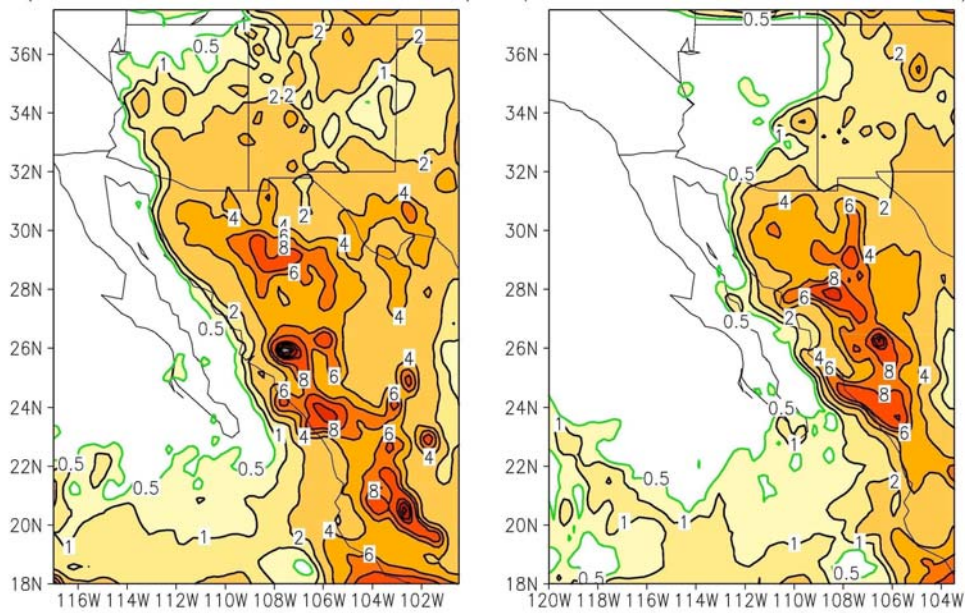
Figure 1

Figure 1 : (a) Mean precipitation simulated by the 20-km RSM for Mexico and the Southwest for the 1990 August. Contour interval is 2 mm day^{-1} . Contours 0.5 and 1 mm day^{-1} are added, (b) same as (a) with the domain shift 3 degrees to the west.
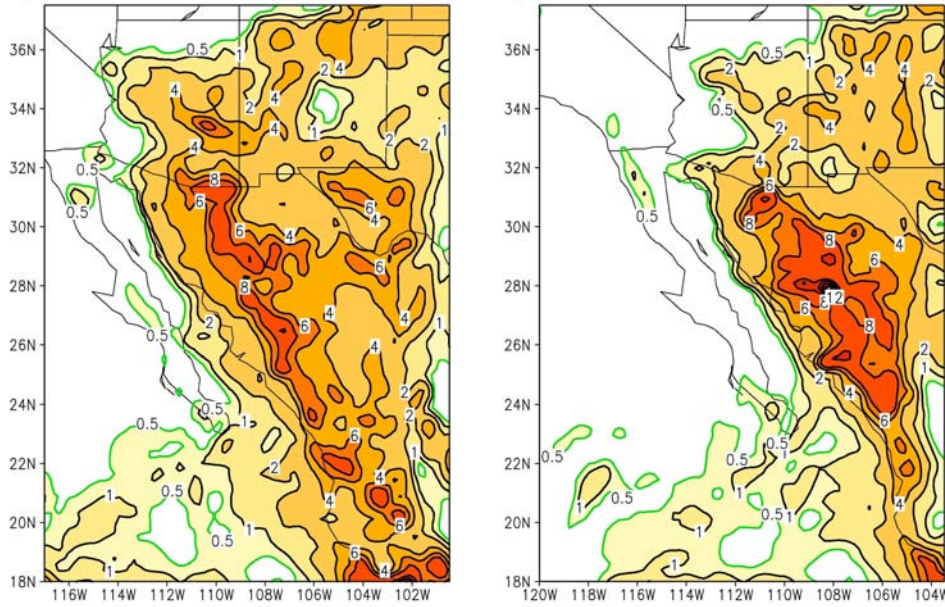
Figure 2

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Figure 2: Same as Figure 1, but after the mean bias correction.

The improved RSM will be used for regional seasonal prediction experiments**.**

3. Examine the relationship between two low level jets and precipitation over the United States.

The summer precipitation regimes over the United States and the roles played by two low level jets are examined using the unified observed precipitation data set, the NCEP-NCAR reanalysis and the 10-yr summer (June-September) simulations based on the 50-km NCEP regional spectral model (RSM) with the initial and boundary conditions provided by the global reanalyses. The quality at regional scales of the RSM simulations is assessed by comparing with the NCEP=s operational Eta Data Assimilation System (EDAS) analyses. The RSM, as EDAS, captures the seasonal evolution of the North American monsoon rainfall and the related vertically integrated moisture fluxes, but details differ. The fluxes associated with the Great Plains low level jet (GPLLJ) and the Gulf of California low level jet (GCLLJ) depicted by two models are similar, but the 50-km RSM has difficulty to capture the vertical structure of the meridional moisture flux associated with the GCLLJ.

The dominant summer precipitation regime is a three cell pattern that consists of an inverse phase relationship between the Great Plains and the core monsoon region with an additional weak center over the southeastern United States. Over the southwestern United States, Arizona and New Mexico belong to two different rainfall regimes and have different moisture sources.

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The out of phase precipitation relationship is consistently related to an out of phase relationship between the two LLJs, whose variations are in turn associated with the upper level jet streams. While strong GCLLJ cases imply a weaker GPLLJ and less rainfall over the central United States and the Mississippi Valley, the strong GPLLJ cases only imply weaker meridional moisture fluxes from northern Mexico or Gulf of California to the southwestern United States and less monsoon rainfall. However, it does not have impact on the moisture fluxes along the Gulf of California.

4. The influence of tropical forcing and soil moisture on summer precipitation regimes over North America

   a) **Precipitation regimes over North America**

Precipitation regimes over North America are determined based on rotated EOF analysis on pentad rainfall data from 1979 to 2002. A square root transformation is applied to rainfall data before entering the REOF analysis. The leading REOFs are given in Fig.3

REOF 1 shows a phase reversal between the P anomalies over the Northern Plains and the Southwest and the Southeast. This pattern has been observed on the time scales from pentads to monthly to seasonal means.
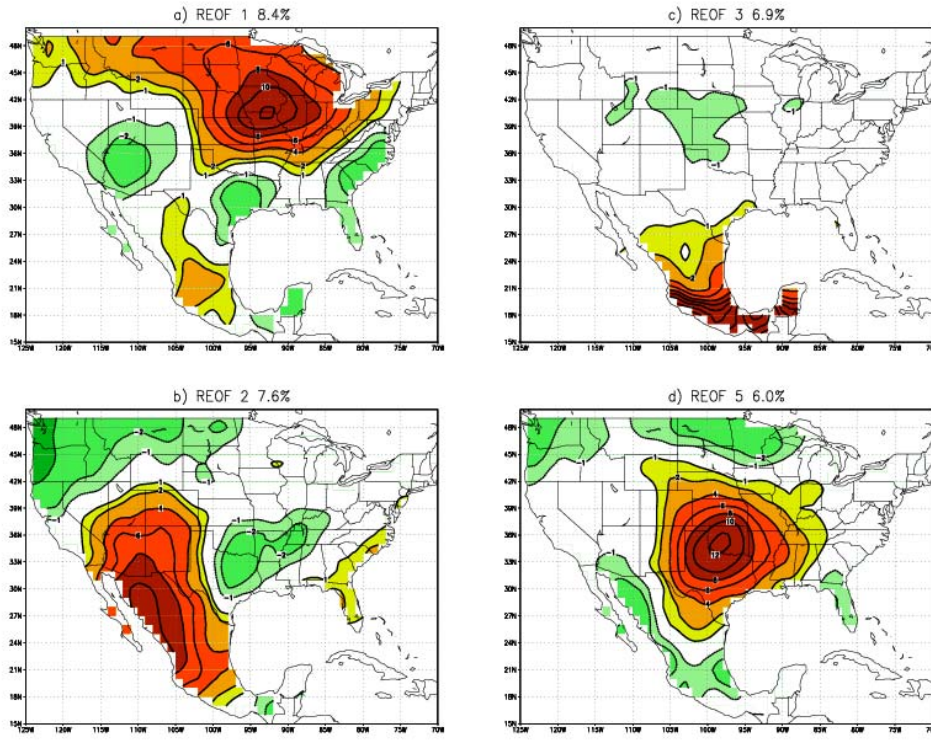
Figure 3

Figure 3: (a) Rotated EOF 1, (b) REOF 2, (c) REOF 3 and (d) REOF 5 for the pentad precipitation for JJAS based on the unified precipitation gridded analysis (Higgins et al.2000) from 1979 to 2003. Contour interval 2 non- dimensional unites. Contours 1 and –1 are added. Zero contours are omitted.

REOF 3 shows rainfall over southern Mexico. That signals the onset of the North American monsoon. REOF 2 and REOF 5 are in quardrature with each other. Both show the phase reversal between rainfall over northwestern Mexico and the southern Plains, but the centers of action differ. REOF 4 shows rainfall over the Southeast. It will not be discussed here.

b) Tropical influence

Positive and negative events were chosen based on RPCs. The criterion is 1.2 standard deviations. Composites of OLRA and 200 hPa streamfunction were formed for positive and negative events separately to examine the linkages to tropical forcing.
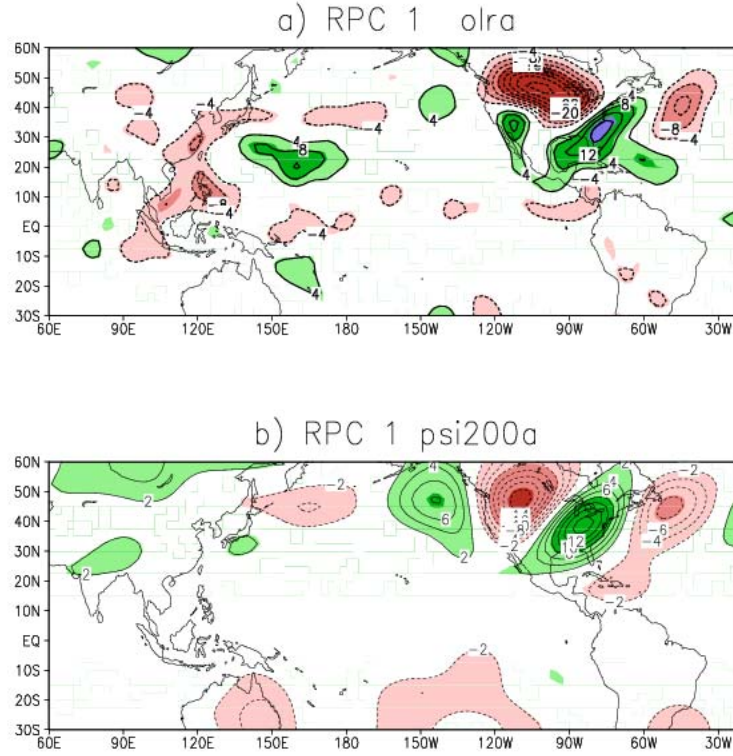
(i)   REOF 1

Figure 3

Figure 4: (a) Composite OLRA difference between positive and negative events based on RPC 1. Contour interval is 4 W m⁻² .Zero contours are omitted. Areas where anomalies are statistically significant at the 5% level are shaded, and (b) same as (a), but for 200 hPa streamfuncion. Contour interval is 2x10⁶ m²s⁻¹

The direct tropical influence on REOF 1 is weak. The OLRA composite difference between positive and negative events for the period from 1979-2002 (Fig. 4a) shows a three -cell pattern consistent with REOF 1 locally, but there is no coherent pattern in the Tropics. This suggests a weak influence of tropical forcing. The corresponding composite difference of the 200-hPa streamfunction anomalies shows a local wave train in the zonal direction with positive anomalies east of the Gulf of Alaska, negative anomalies over the western region and positive anomalies over the central and eastern United States and negative anomalies in the Atlantic (Fig. 4b). The composites with OLRA leading RPC 1 from day -20 to day 0 also do not show strong tropical forcing. However, results here do not rule out the possible that the low frequency component of tropical forcing on seasonal time scales sets up favorable conditions for the strengthening of the north American jet, which in turn influences the GPLLJ and rainfall over the northern Plains.

(ii) REOF 3

REOF 3 is influenced by tropical convection in the Pacific. The composite of OLRA (Fig.5) indicates that strong convection (negative OLRA) in the tropical Pacific is associated with less rainfall over southern Mexico. Both ENSO and the MJO can produce such OLRA pattern. This is consistent with reports by Higgins et al. (1998), Higgins and Shi (2001) that monsoon rainfall over southern Mexico is influenced by ENSO. More (less) rainfall occurs during the cold (warm) ENSO events or during the phase of the MJO with suppressed convection in the central Pacific. The reason is that the downward branch of the Walker circulation associated with convection over the central Pacific is located over southern Mexico as indicated by the divergent wind anomalies. Therefore, there is less rain over southern Mexico. Less rainfall over southern Mexico means a weaker Haldey circulation. The descending branch of the Hadley circulation is located over the central United States. Less rainfall over southern Mexico means more rainfall over the central United States.
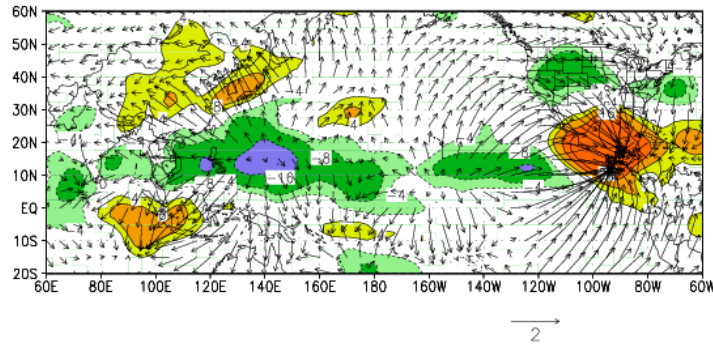
Figure 5

Figure 5: Composite OLRA difference between negative and positive events based on RPC 3. Contour interval is 4 W m^{-2} .Zero contours are omitted. Areas where anomalies are statistically significant at the 5% level are shaded. Vectors are divergent wind anomaly differences between negative and positive events. The unit vector is 2 m s^{-1}

(iii) REOF 2 and REOF 5

Both REOFs are influenced by tropical convection over the Indian and Pacific sector. For REOF 2, the OLRA shows a three-cell pattern in the meridional direction with positive anomalies over Central America, negative anomalies over northern Mexico and positive anomalies to the north. This phase of REOF 2 is associated with positive OLRA with one branch extending from the Indian Ocean to Philippines and another branch extending to Japan (Fig.6a). There are also negative OLRA centered over the area centered at 15 -20ºN, 150ºW. Both OLRAs in the interannual and intraseasonal bands

contribute to the composite (Figs.6a and 6b). Higgins and Shi (2001), and Mo (2000) both show that the major influence of the MJO is over the Mexico and southern Plains, which will have projection on REOF 2. The associated atmospheric pattern shows negative anomalies in the subtropics with positive anomalies to the North. Over North America, there are negative anomalies centered over 45ºN, 120ºW and positive anomalies over Baja California and northern Mexico (Fig.6c).
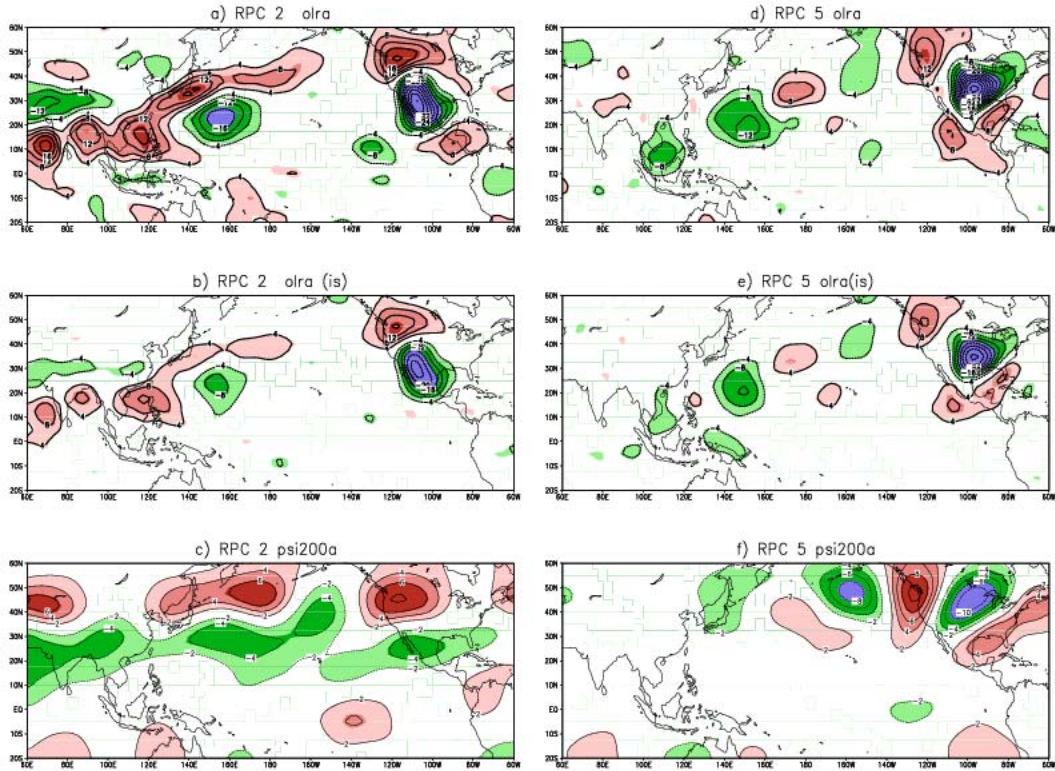
Figure 6

Figure 6: (a) Composite OLRA difference between positive and negative events based on RPC 2. Contour interval is 4 W m^{-2} . Zero contours are omitted. Areas where anomalies are statistically significant at 5% level are shaded, and (b) same as (a), but for 10-90 day filtered OLRA, and (c) same as (a), but for 200 hPa streamfuncion anomalies. Contour interval is $2x10^6$ m^{2}s^{-1}. (d)-(f) same as (a)-(c), but for REOF 5.

The comparison between composite differences of the total OLRA and 10-90 day filtered OLRA based on REOF 5 indicates that REOF 5 is mostly influenced by tropical convection in the intraseasonal band (Figs.6d and 6e). Both show a wave train like

pattern from 10 °N, 110°E propagating northeastward through 20°N,145°W to positive anomalies over the Pacific Northwest and negative anomalies over the southern Plains and positive anomalies over Central America. The corresponding 200 hPa streamfunction composite difference (Fig.9f) shows a wavetrain from north of negative OLRA (25°N, 135°W) to North America.   Both the MJO and a submonthly oscillation with the period of 20-28 days contribute to the convection pattern.

c) Influence of soil moisture

It is interesting that rainfall over the northern Great Plains (REOF 1, Fig.4a) and over the southern Plains (REOF 5, Fig.4d) belong to two different regimes. REOF 1 is not associated with strong tropical forcing, but is influenced by soil moisture over the entrance region of the GPLLJ. To illustrate that, Fig.7 shows the composite differences of soil moisture from the surface to 100 cm from day –15 before to 20 days after the onset of events (colored), and the composite difference of the corresponding vertically integrated meridional moisture fluxes [qv] (contoured). The soil moisture anomalies were obtained from a land data reanalysis (LDAS) using the EMC Noah model (van den Dool et al. 2003) and the [qv] were obtained from the CDAS/reanalysis (R1). Both data cover the period from 1968-1996.

About 15 days before the onset of positive RPC 1 events, positive soil moisture anomalies start to build up over Texas and at that time, the GPLLJ is near normal. As time progresses, the soil moisture anomalies intensify and expand northward to cover the southern Plains and the GPLLJ starts to organize near the border of Texas and Mexico. As GPLLJ establishes at the Gulf of Mexico, it strengthens and extends northward into the central United States. The moisture convergence brings rainfall in the northern Great Plains. Only after rainfall starts, soil moisture increases over the northern Great Plains and persists. After day 10, the GPLLJ decreases in magnitude, but soil moisture anomalies persist through day 20. This confirms the studies by van den Dool et al. (2003), and Mo and Juang (2003) that the influence of soil moisture upstream at the entrance of the GPLLJ is more important than soil moisture over the northern Great Plains in supporting rainfall over the northern Great Plains.
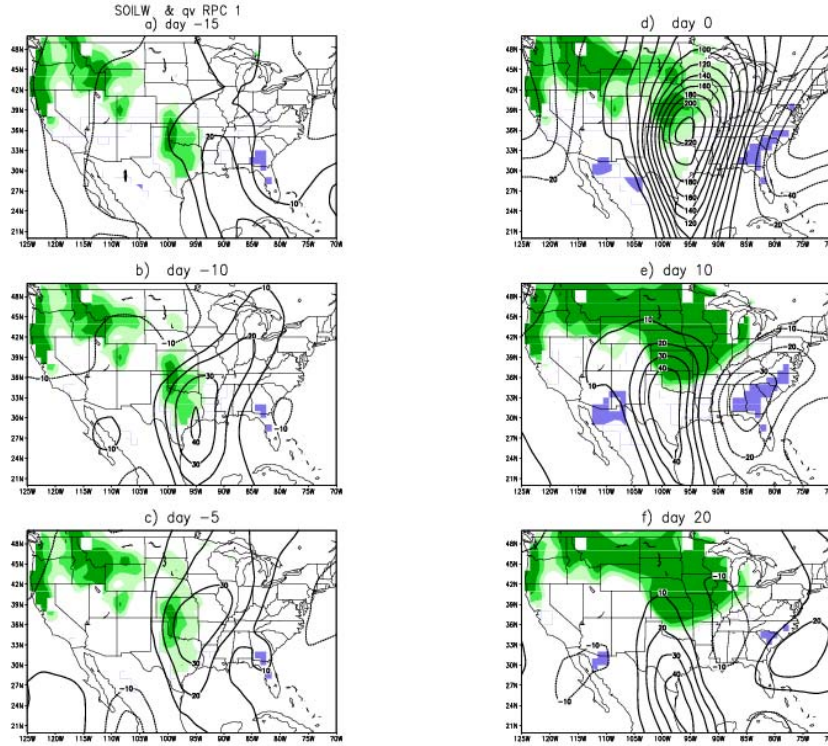
Figure 7

Figure 7: Composite differences of soil moisture anomalies from 0-100cm (colored) and vertically integrated meridional moisture fluxes from (a) day –15, (b) day –10, (c) day –5, (d) day 0,(e) day 10 and (f) day 20. Darker color means stronger positive soil moisture anomalies. [qv] s are contoured every 20 kg (ms) $^{-1}$

The influence of soil moisture on rainfall over southern plains is very different. There is no soil moisture building up before the onset of rainfall events. The GPLLJ starts to strengthen at day –2 and reaches a maximum at day 0 consistent with the relationship between the GPLLJ and rainfall. The soil moisture anomalies start to increase only after rainfall events. The increase of soil moisture over the southern Plains is the results of heavy rainfall.
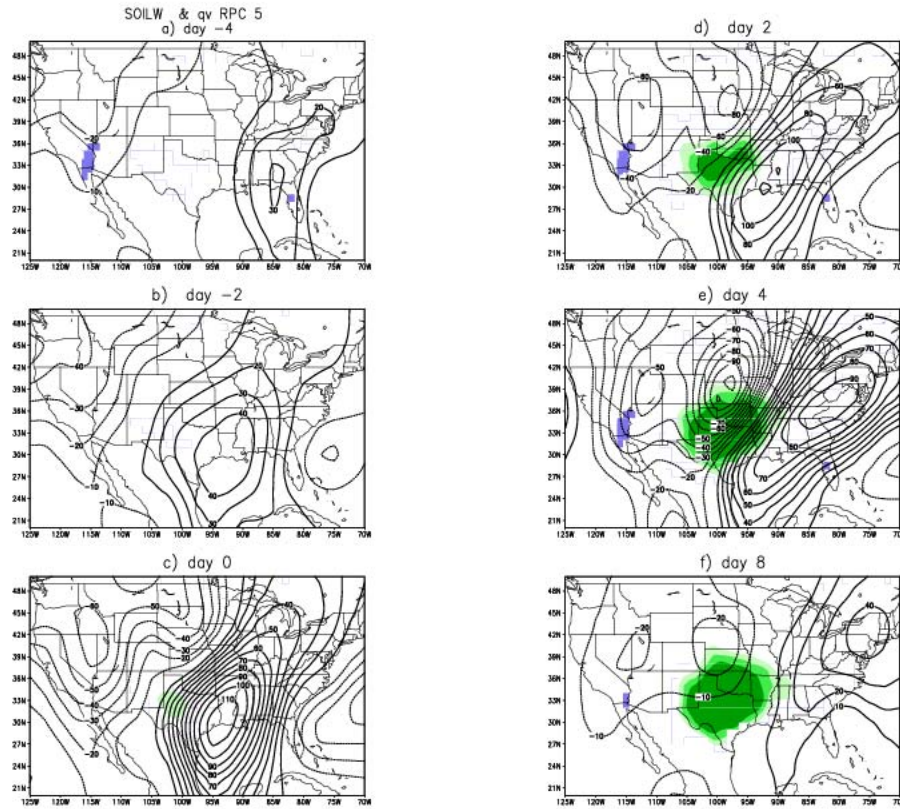
Figure 8

Figure 8: same as Figure 7, but for (a) day –4, (b) day –2, (c) day 0, (d) day 2, (e) day 4 and (f) day 8 from onset of REOF 5.

5) Future plans

During next year, we will concentrate on the seasonal forecasts. We will test the horizontal and vertical resolution needed to capture the monsoon rainfall over Mexico and the southwestern United States.

a) Test the impact of model resolution:

The most recent global forecast model (GFS) at the NCEP will be used for testing. It has improved radiation package and better convection in comparison with the seasonal forecast model (SFM). We will test the influence of horizontal and vertical resolutions of the model on summer precipitation over North America. Four case studies are chosen: 1990,1993, 1999 and 2003 summer. The 1990 summer is the NAMAP year, and the 1993 summer had flooding over the Great Plains. The year 1999 was a strong monsoon year and 2003 was a weak monsoon year.

The models tested have the resolution (i) T62L28, (ii) T62L64, and (iii) T126L28. The T62L28 is the control run since that model will be used for the

seasonal forecasts at the CPC. These models are chosen because that the T62L64 model has better tropical intraseasonal oscillations and the T126 model has enough resolution to resolve the GCLLJ. If results are not satisfactory, we will go to higher resolution if needed.

b) Test the impact of radiation:

At this moment, the long wave radiation routine was called every 3 hours. We will test whether the diurnal cycle will be better resolved if the radiation routine is called more often.

c) Test the best way to perform regional seasonal forecasts: high-resolution global model (T126L28 or T170L28) versus RSM downscaling.

The purpose is to compare the regional seasonal forecasts using a very high-resolution global model T170L28 model and forecasts with a coarse model (T62L28) followed by regional model downscaling. These experiments are designed to test the benefit of downscaling.

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